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BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE

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THE RELATION OF FOREST INSECTS AND TREE VIGOR IN THE MANAGEMENT OF JACK PINE IN THE LAKE STATES

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Although jack pine, Pinus banksiana Lamb., is found on the best sites and grows well on them, it is generally considered to be a pioneer tree coming in after fires on the sandiest of soils. It is not a long lived tree in comparison with white pine and red pine, but because of the heavy cutting of these species about the end of the last century and their relative scarcity in recent years jack pine has become a rather valuable tree in the present forest economy of the Lake States region. It commands a good market for mine timbers, pulp, and rough building construction. On the better sites it does not reach maturity until 80 to 100 years old, but on the poorer sites - and these cover many thousands of acres - decline in vigor sets in at about 50 years and soon thereafter the stands begin to break up. In 1938 mortality became noticeable in mature stands on the Cut Foot Experimental Forest located in that part of the Chippewa National

1/ Much of the information on the occurrence of the budworm in northern Minnesota is based on observations made by L. W. Orr and R. H. Nagel, of the Division of Forest Insect Investigations, while they were stationed in the Lake States. Assistance in collection of the data and suggestions concerning the discussion on growth were given by P. J. Zehngraff and S. R. Gevorkiantz of the Lake States Forest Experiment Station. The writer is indebted to all four for information and assistance.

Forest lying in Itasca County, Minnesota, and the following year large numbers of jack pine trees appeared to be in a decadent condition. Some older trees were scattered throughout the forest but the stand as a whole was in the 60- to 80-year age classes and came in after a severe fire. According to Indian history this fire, known as "The Fire of Two Summers" started at Black Duck in the fall of 1863 and was driven south before a northwest wind. The legend is that the fire held over in the peat bogs during the winter and was driven back over the same area the following summer by a southwest wind. The relative absence of charred wood indicates that all the litter and dead wood must have been almost completely destroyed by the fires. The exposed mineral soil then offered an excellent germinating medium for an abundant supply of jack pine seed.

Many people believed that the jack pine form of the spruce budworm, Archips fumiferana (Clem.), was the cause of this tree mortality and decadence. Defoliation first became noticeable in June 1937 and on July 9 Orr reported that it had been limited to a comparatively small percentage of the trees in the affected stands and particularly to those trees which had produced a heavy crop of staminate flowers that year. It appeared probable that the attack would be heavier the next year and there was danger of severe defoliation of all trees in the Experimental Forest. In his annual report for 1938 Nagel stated that the infestation had increased in severity on the Cut Foot-Sioux Ranger District, and defoliation had been noticeable over wide areas. In isolated "orchard" stands the budworm feeding on the current season's foliage had been supplemented by that of the jack pine sawfly, Neodiprion banksianae Roh., on the old foliage, and in such cases the defoliation was complete or nearly so. By 1939 the infestation had spread over practically all of this district and into the eastern edge of

the Cass Lake District. The populations of both the budworm and the sawfly were not so dense, however, as in 1938 and consequently defoliation was not so severe. In the annual report for 1939 Nagel stated that the defoliation in 1938 had not been severe enough to cause death although some areas had been very heavily infested. Graham (1) had found that large jack pines usually were not killed, except at the top, by budworm defoliation and because of this and the fact that trees of all crown classes had died in the stands on the Experimental Forest, the writer was of the opinion that other factors were involved. As all these observations indicated a difference of opinion as to the relation of the insects to the tree mortality it seemed that these other factors might prove to be even more important than the insect defoliation and subsequent attack by secondary borers. Previous investigations of decadence of birch (2) and hemlock (3) in timberlands had shown the insect attacks to be secondary to physiological disturbances and it was believed, therefore, that a study of the root systems of a number of jack pine in various stages of vigor might reveal similar conditions and give valuable information leading up to the true causes of the decadence. A solution of the problem might also have a bearing on future suggestions for the management of jack pine.

PROCEDURE

Such a study was planned by the writer and carried out during the summers of 1940 and 1941 in cooperation with the Lake States Forest Experiment Station, the Chippewa National Forest, and the Civilian Conservation Corps Camp located on the Cut Foot-Sioux Ranger District. Although the choice of trees in 1940 had been based on their being alive or dead, it became apparent, when the roots were exposed, that there was a definite relation between the condition of the roots and the vigor of the trees. It appeared possible to establish a set of tree characteristics for determining tree condition by the appearance of the crown. For example in Figure 1 the full-crowned trees at the left are apparently vigorous, whereas less than normal foliage density in the remaining trees indicates a lack of vigor, or decadence. Consequently in 1941 the trees were chosen and allocated to different classes in this manner. To some extent Keen's classification for ponderosa pine (4) was used and the trees were classed as "A", "B", and "C" - the chief considerations being the length, width, and density of the crown itself and the richness in color and the abundance of the foliage. Following the procedure used in the hemlock tree condition study (3) the root systems of 39 trees were exposed and examined - 20 of these being done in 1940 and 19 in 1941. Twenty six of the trees were living and 11 were dead jack pines. The two remaining trees were living red pines which were washed out so that the root systems of the two species could be compared, as red pine is generally supposed to have a deeper root system. The study area is well-drained and exposing the roots was a simple matter. The soil is a very fine sandy loam of the Cass Lake fine sands, overlaying a coarser sand or fine gravel formation and occasionally a clay stratum.

The growth rate of the different classes was determined for three decades. In order to make this as accurate as possible the annual rings were standardized by an analysis of the increment over a period of about 40 years. To do this, cross-sections were removed at stump height as each tree was felled preparatory to washing the soil from the roots. The examination of these sections showed that narrow rings and wide rings in certain years could be correlated quite easily with weather data. As a further check on the relation between the crowns and the roots, all the foliage and small branch tips and the smaller roots of a number of trees were removed and later weighed.

STUDY OF THE TREE CONDITIONS

In the first year's investigation 5 lateral roots were chosen at random as soon as each root system was exposed, and the number of living and dead root tips was determined. Examination proved that there was a noticeable difference in appearance between the living and the dead tips even on trees that appeared to be vigorous. Many of the tips, and in some cases entire roots, had died prior to 1938 and histological sections showed that a great deal of the root mortality occurred in 1936 - a year of almost unprecedented drought conditions. The more vigorous trees had fewer dead tips than did those that appeared to be decadent. Cankers, which were similar to those common on the roots of decadent hemlock on the Menominee Indian Reservation, were found only occasionally. The shoestring root rot was also very scarce, probably because all the dead wood had been burned at the time of the great fire and very little material suitable for its existence was available for a long period of years. The exposure of the lateral roots, shown in Fig. 2, revealed the fact that there is a mass of interlacing roots in the first few inches of the upper soil. They are wide-branched so as to obtain the maximum

amount of water and nutrients near the surface of the soil, and they literally fill the spaces between trees. The 1940 work had shown that jack pine may possess a definite tap root and in addition vertical roots which arise from the laterals outside the root crown. These were not completely exposed at the time and as the exact nature of their tips had not been determined this was done in 1941. Figure 3 shows the development of these deep roots. Tree number 40 was about 70 years old and was marked as a vigorous tree prior to felling and washing. It had a vigorous appearing crown and was classed as an "A" tree before cutting. This tree was in the middle of one of a series of plots established in the fall of 1939 for the purpose of studying the effects of different degrees of cutting on the remaining trees. As the trees were marked for cutting, the crown condition of the trees to be left for observation was indicated in the notes as a percentage of defoliation, although this was not necessarily attributed to insects. The tally sheets showed this tree as "100 percent defoliated and dead", and as it obviously was a living tree, other trees in the same plot were checked and it was found that certain ones checked as 50 to 90 percent defoliated had apparently recovered and had full crowns whereas others listed as 25 to 50 percent defoliated had died or were decadent. This seemed to indicate that other factors, besides insect defoliation, entered into the deterioration of the stands. Weaver (5) found that under drought conditions plants have to rely in great measure on the available water in the deeper soil strata. In these jack pine stands under drought conditions the root competition must have been tremendous, and when the available soil moisture and the soluble nutrients were exhausted from the upper stratum containing the lateral roots, it is obvious that each tree was affected in a degree dependent on its ability to obtain water and nutrients through deeper roots in the lower strata. Tree

number 27 had a more definite tap root than did tree number 40 but it also had several vertical roots. Its crown was well developed and it was classed as an "A" tree without any question at the time the trees were marked for cutting and washing. In contrast the root systems of the dead trees were very definitely not so well developed. It appears evident that the deep root system on tree number 40 may have been the deciding factor in enabling it to return to a state of vigor. As there was a very definite difference in the density of the crowns and also in the development of the roots in trees of the various stages of vigor it was also deemed necessary to weigh the foliage and root tips of some of the trees. Lack of time and labor prevented the removal of the individual needles so the branch tips were taken. Only the tips of the roots were used, as the larger portions of the roots were considered in the same category as larger branches. In table 1 it is apparent there is a close correlation between the weights of these parts of different trees.

Table 1.- Comparison of the size of the crown and roots of jack pine trees in different stages of vigor.

TREE CLASS	NUMBER OF TREES	CROWN			ROOTS			
		Length in feet	Width in feet	Weight of foliage and branch tips in pounds	Length in feet	Width in feet	Weight of tap and vertical root tips in pounds	Weight of lateral root tips in pounds
A	5	29.2	16.6	91.00*	7.8	5.2	17.62*	12.75*
B	5	30.6	13.6	64.25*	6.1	4.0	15.87*	8.06*
C	7	24.3	9.1	46.50*	5.8	2.6	8.84*	6.25*
Red Pine	1	36.0	19.0		7.5	4.5		

* See top of page 8

*The weight of the foliage is based on one tree in each class; the weight of the root tips is based on three trees in class A, two trees in Class B, and one tree in class C.

It is of interest to note that Adams and Chapman (6) working in a 28-year old jack pine plantation on sandy soil in Vermont found vertical roots which arose from the lateral roots outside the crown collar, but no tap roots. In this study very definite vertical roots, as well as tap roots were found (Fig. 4).

The study of the cross-sections produced evidence which seems to indicate that the decline in vigor of the jack pine in these stands began prior to the budworm infestation. As some of the class "C" trees had failed to lay on wood after 1938 all measurements were made by decades back from that year. Previously by standardizing the rings it had become evident that a stem analysis would give more accurate information than a study of the increment cores used in 1940. Using a planimeter to get the circumference at stated intervals, the increase in basal areas by decades was computed. Table 2 shows that in the best trees, those considered as "A" trees, the rate of increase in basal area was greatest; the "B" trees just about held even, while the "C" trees very definitely lost ground.

Table 1.- Comparison of increase in basal areas of cross-sections from trees washed out in 1941

Class	Number of trees	Average age in 1941	Average height in ft. in 1941	Average d. b. h. in in. in 1941	Basal area increase by decades in square inches		
					1909 1918	1919 1928	1929 1938
A	5	69	69	11.22	5.73	6.02	6.56
B	5	72	65	10.96	4.24	4.21	3.95
C	7	67	63	8.96	4.02	3.38	2.86
Red Pine	1	70	75	13.80	9.22	8.70	11.12

CONSIDERATION OF THE CLIMATIC FACTORS

As this study of the roots, crown, and the annual increment showed that budworm defoliation beginning about 1937 occurred some time after the jack pine trees began to decline in vigor, it seemed very probable that climatic factors had played an important role in this decline. Precipitation and temperature play a potent part in the development and continuance of a forest. During periods of severe drought and high temperatures many more roots die than during normal conditions. Kramer (7) is authority for the belief that "when environmental conditions favor rapid transpiration, cessation of root-extension for only one or two days would result in death of many, and probably most plants, from desiccation." Salter (8) commenting on this statement says that "from the foregoing it is evident that the ability of trees to resist drought will depend not only on the amount of available water held by the soil, i.e., the spread between field capacity and wilting point, but equally important, upon the volume of soil permeated by the roots and the presence or absence of impediments, either mechanical or physiological, to rapid root extension. Obviously also, the frequency and ease of renewal of available water in areas desiccated by root absorption through the processes of infiltration and percolation may be highly important." This would be of particular importance in the case of the shallow rooted jack pines.

Precipitation records at the Weather Bureau Station maintained by the U. S. Engineers Corps at the Minnibigoshish Dam, about 8 miles air-line from the Experimental Forest show that there has been a remarkable deficiency in moisture over a long period of years. In considering this factor , both annually and for the growing season of April to August

inclusive, one finds that precipitation during the decade 1909 to 1918 was 15.03 inches below normal for the entire annual period and 4.87 inches below normal for the growing season. However, the deficiencies for these periods in 1917 and 1918 collectively were 18.95 inches and 12.59 inches respectively. Beginning in 1917, when the annual deficiency was 11.67 inches, the total deficiency for the 22-year period to 1938 was 80.85 inches with only 1919, 1928, and 1937 precipitation being above normal. Again, beginning in 1917, when the deficiency in the growing season was 8.47 inches, the total deficiency for the same 22-year period was 43.61 inches. Better than normal precipitation, however, occurred during the growing season in 1919, 1920, 1927, 1928, 1935, and 1937. In order to have the very large total deficiencies just mentioned, the minus departures in the other years had to be large also. These records were taken in the open and when one realizes that approximately 20 percent of the rainfall is held in the tree crowns and evaporates (9), the reduction in available soil moisture becomes even more serious. Coupled with the moisture deficiencies in such years as 1936, when the departure for the growing season was -7.61 inches, there were certain very warm periods. For example, the Minnesota Climatological Report stated that July was "noteworthy and without parallel for its persistent heat and lack of moisture". At Winnibigoshish Dam the temperature rose to 102° F. on July 11, 12, and 13, and no rain fell from the first to the fifteenth. August was considerably warmer than usual, several days having a maximum temperature of 90° F. or above, and no rain fell from July 27 to August 14. At Cass Lake, Shirley and Meuli (10) recorded a precipitation of only 1.21 inches from July 1 to August 27, and during the latter part of the period the soil moisture in many cases was but little above the wilting coefficient. It is common knowledge that the

upper soil was powdery dry and to a depth of six inches the light sandy soil would flow freely through the fingers. The mortality in plantations set out that spring and the previous fall was very high, and studies by the Lake States Forest Experiment Station (11) showed that the excessive heat had been even more injurious than the lack of moisture.

It seems reasonable to postulate that these two weather factors must have had a tremendous damaging effect on the shallow rooted jack pines and that they very probably were the most important in the chain of events leading up to decadence of this species after it had begun to decline in vigor. Undoubtedly there are sites where jack pine will grow profitably beyond the age of 70 to 80 years, but it is probable that in the majority of cases it should be managed on a shorter rotation. This will be particularly true on sites where the lateral roots are close to the surface of the soil, and the tap and vertical roots are not deep. When a jack pine stand is approaching maturity it should be marked to remove in the first cut all those trees which are obviously not "earning money". This is especially the case when there is a period of moisture deficiency such as occurred in Minnesota during the past quarter century.

SUMMARY

To determine the reasons for mortality of jack pine in the older stands on the Cut Foot Experimental Forest, Chippewa National Forest, Minnesota, a tree condition study was carried on during the summers of 1940 and 1941. The root systems of 37 jack pines were washed out and examined.

Those trees which had died or were decadent, invariably had shorter tap and vertical roots and, in addition, less developed lateral roots than

did the vigorous living trees. There is a very definite relation between the condition of the roots and the vigor of the tree. A "visible indication" classification - by crown vigor - permitted an accurate prediction of the root condition. There was a correlation between the weight of the foliage and the weights of the lateral roots and the tap and vertical roots.

Precipitation records for a period of 30 years showed that there was a period of 10 years of approximately normal precipitation followed by 20 years of drought or near-drought conditions. Lack of moisture undoubtedly had an important effect on the shallow-rooted jack pines during this period. This is borne out by the narrow annual rings. The basal areas of trees in different classifications were determined. The rate of increase in the best trees was progressively greater in each of the three decades considered, while that of the poorest ones decreased very materially.

Although budworm defoliation, on the basis of the data obtained in this study, was not the primary cause of the death of the jack pine, it very probably played an important part in the final stages of decadence in weakened trees.

The shoestring root rot was not an important factor in tree decadence in the study area.

A very marked moisture deficiency, with severe drought conditions at various times, and high temperatures during periods when there was no precipitation, caused great mortality of feeding roots and played a major role in causing decadence. This was the case in 1936, especially, when a large percentage of the root tips died.

Except on the best sites, Jack pine normally begins to decline in vigor at about 50 years. When this decline becomes apparent, and particularly during a period of moisture deficiency, the stand should be marked so as to remove the unprofitable trees.

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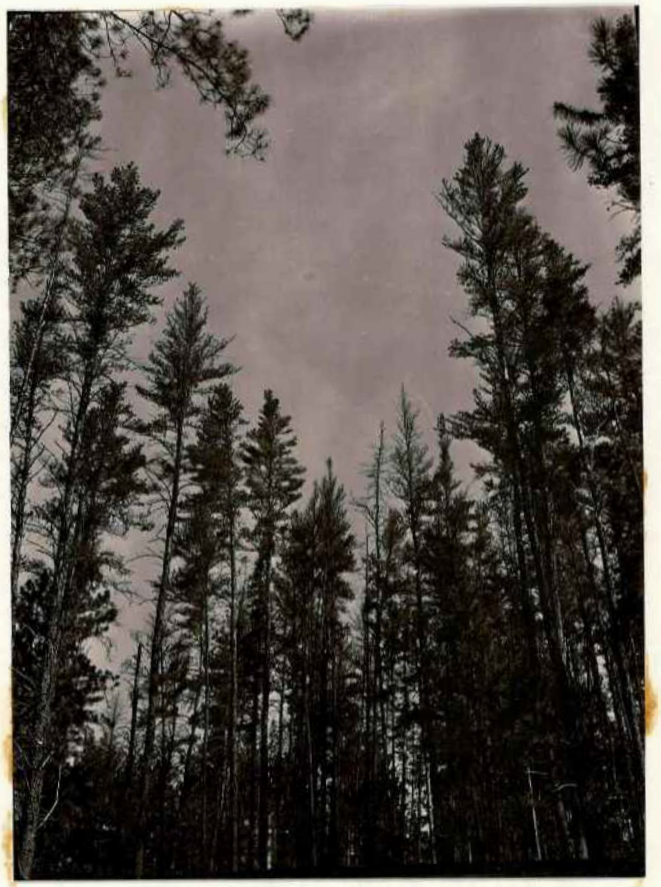

Fig. 1.- The full-crowned trees, at the left, are apparently vigorous, and would be classed as "A" trees. The trees in the background, having dead tops or thin crowns, would be classed as "C" trees.

Fig. 2.- Jack pine, growing under the conditions described in this paper, has a maze of wide-branched lateral feeding roots near the surface of the soil.

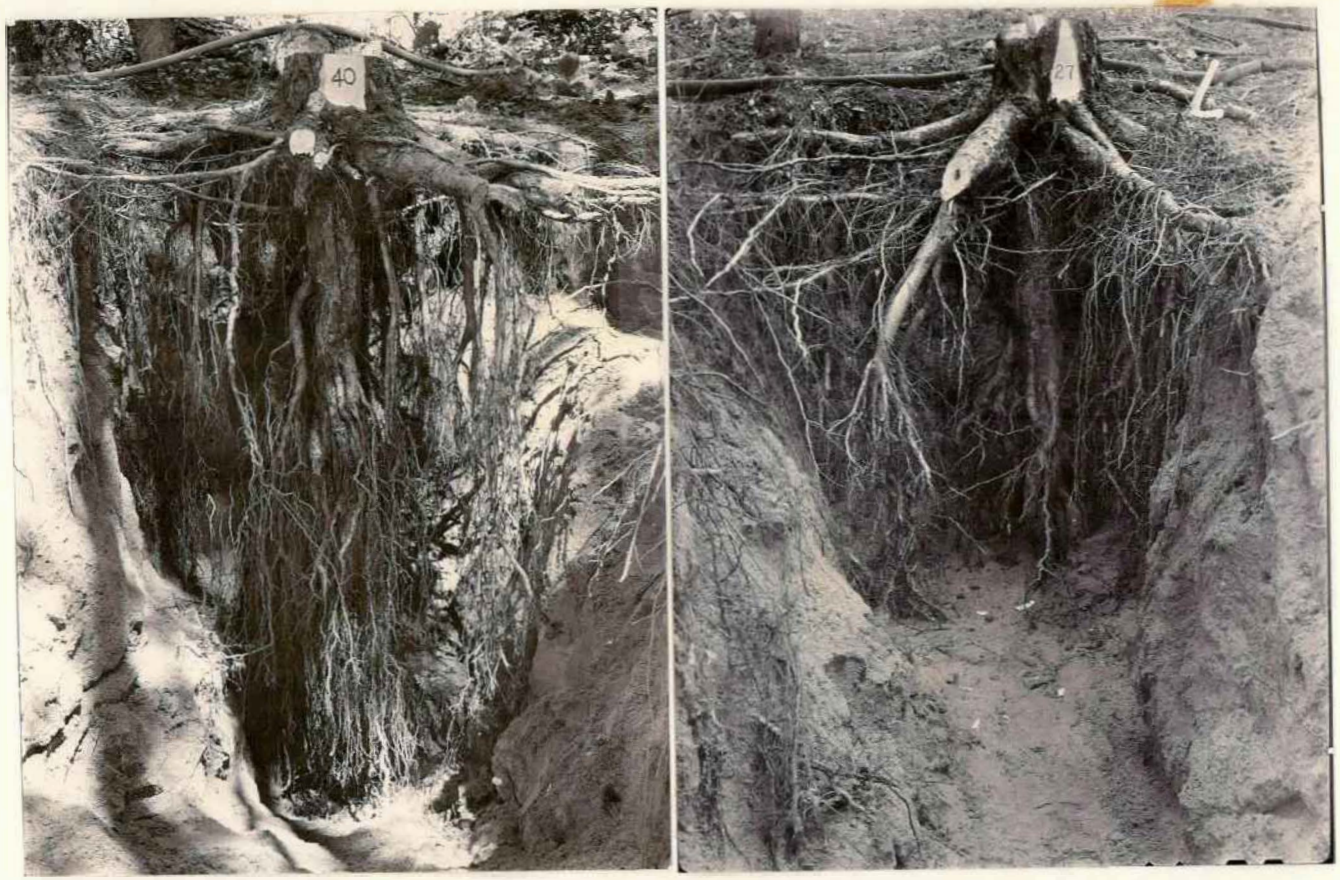

Fig. 3.- Two exposed root systems showing the development of deep roots to reach the subsoil moisture. Such roots enable a tree to continue growing during drought conditions even with a lowered water table.

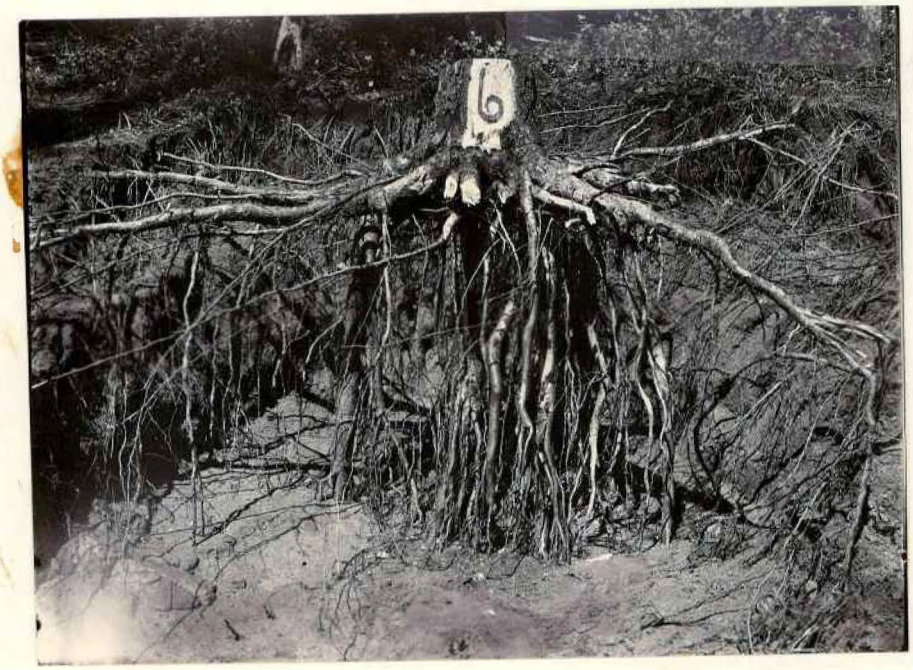

Fig. 4.- The extensive vertical and tap roots of a vigorous tree washed out in 1940. The root tips were succulent, indicating that water, and perhaps leached nutrients, can be removed from the deeper soil strata. Although the upper crown was dead, probably the result of budworm defoliation, the 1940 foliage was vigorous and the radial increment in the period 1929-1938 was greater than during either of the two previous decades.